

THE REGISTRATION OF EARTHQUAKES
AT THE BERKELEY STATION

AND

AT THE LICK OBSERVATORY STATION

FROM

October 1, 1920, to March 31, 1921

BY

LEWIS A. BOND

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SYMBOLS AND NOTATIONS

1. Character of the Earthquake—

I. Perceptible. II. Moderately strong. III. Strong.

d (terrae motus domesticus)	Local shock (origin less than 100 kilometers distant).
v (terrae motus vicinus)	Near shock (origin from 100 to 1,000 kilometers distant).
r (terrae motus remotus)	Distant shock (origin from 1,000 to 5,000 kilometers distant).
u (terrae motus ultimus)	Very distant shock or teleseism (origin more than 5,000 kilometers distant.)

2. Phases of the Seismogram—

P (undae primae)	First phase, or first preliminary tremors.
PR _n	Waves n-times reflected at the earth's surface.
S (undae secundae)	Second phase, or second preliminary tremors.
SR _n	Waves n-times reflected at the earth's surface.
PS	Waves changed from longitudinal to transverse oscillation, or vice versa, through reflection at the earth's surface.
L (undae longae)	Long waves, chief phase, or principal part.
M (undae maximae)	Greatest motion in the chief phase.
C (coda)	Tail or end portion.
F (finis)	End of discernible movement.

3. Nature of the Motion—

i (impetus)	Sudden beginning of the motion.
e (emersio)	Gradual beginning of the motion.
T (period)	Time of one complete oscillation.
A	Amplitude of the motion, measured from the median line in microns ($\mu = 1/1000$ mm.).
A _E	E-W component of A.
A _N	N-S component of A.
A _V	Vertical component of A.

4. Time—

O (origin)	Time of shock at point of origin.
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THE BERKELEY STATION

CONSTANTS

Latitude and longitude of the center of the seismographic room:

$$\phi = 37^{\circ} 52' 15.''9 \text{ N. Lat.}$$

$$\lambda = 122^{\circ} 15' 36.''6 \text{ W. from Greenwich.}$$

Time. All determinations are reduced to Greenwich mean civil time.

Altitude, 85.4 meters (280 feet) above mean sea-level.

CONSTANTS OF THE SEISMOGRAPHS

	Period	Magnif.	Damping
Bosch-Omori Seismograph N-S component.....	15 ^a	80	8-1
Bosch-Omori Seismograph E-W component.....	15 ^a	80	8-1
Wiechert Seismograph Vert. component.....	6 ^a	80	8-1
Omori Tromometer N-S component.....	2 ^a	60
Omori Tromometer E-W component.....	2.5 ^a	60
Marvin Strong-motion Seismograph—			
E-W component.....	6.5 ^a	5.8	1.3-1
N-S component.....	6.5 ^a	5.1	1.4-1



No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A _E	A _N	A _V	
	1920			h m s	s	μ	μ	μ	
1	1 Oct.	I?	e _E e _N F	19 06 37 19 06 54 19 34±	15 15				Trace of main phase of a distant quake. Time marker on V out of order.
2	5 Oct.	III _v	eP _v eP _{E,N} M _N M _v M _E F	19 04 48 19 04 49 19 05 35 19 05 37 19 05 54 19 19±	2 2½ 2	132	303	55	Started Marvin strong-motion instrument. Felt at San Jose and in neighboring towns. Beginning of L can not be satisfactorily determined. See Lick Observatory station No. 3.
3	8 Oct.	I?	e _v e _E F	16 57 44 16 57 37 17 26±	22				Trace of main phase of a distant quake. Not recorded on N-S.
4	12 Oct.	I?	e _E e _N e _v F	17 52 50 17 52 52 17 53 21 17 59±					Faint record of a local shock.
5	18 Oct.	I _u	o eP _{NV} eP _E iS _N iS _E iS _v M _E M _N F	8 11 37 8 22 02 8 22 04 8 30 29 8 30 30 8 30 31 8 30 33 8 30 35 9 47±					Δ = 6960 km. S (?) begins with sudden displacements on the horizontal components and these culminate in the maximum amplitudes observed. Beginning of L could not be located.
6	22 Oct.	I _r	eP _v eP _{EN} eL _N eL _E eL _v F	12 21 48 12 21 49 12 31 36 12 31 37 12 31 49 12 57±					Δ = 3860 km. Trace of a distant quake. Amplitudes very small throughout.
7	28 Oct.	I?	e _N e _v e _E F	7 42 01 7 45 44 7 46 31 8 12±	12 17				Flat waves with superimposed microseisms.
8	28 Oct.	I _u	eP _v eP _{NE} eL _N eL _v eL _E F	13 02 22 13 02 23 13 28 57 13 29 23 13 29 29 14 15±					Distant quake registered faintly on all components. Amplitudes very small.
9	16 Nov.	I?	eP _v e _{N,N} F	8 37 48 8 43 19 9 12±					Trace of distant quake on all components. Periods during main phase vary from 15" to 20".

No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A _E	A _N	A _V	
	1920			h m s	s	μ	μ	μ	
10	24 Nov.	I?	e _v e _{E,N} F	12 02 11 12 02 12 12 03 46					Trace of weak local shock on all components.
11	28 Nov.	I?	e _{N,v} eL _E M _v M _N M _E F	11 35± 11 36 27 11 38 15 11 38 08 11 39 04 12 02±				Beginning and ending obscured by micros.	
12	29 Nov.	I _r	eP _{E,v} e _N e _v eL _E F	8 08 53 8 09 15 8 13 01 8 14 08 8 31±				Trace of a distant quake on all components.	
13	5 Dec.	I?	e _N e _E e _v F	11 59 43 12 00 33 12 00 39 12 08±					Local shock. Phases not discernible. Period about 2" during principal portion.
14	10 Dec.	I?	e F	5 08± 5 51±					Trace of main phase of distant quake. Heavy and persistent microseisms superimposed.
15	11 Dec.	I?	e F	21 42± 21 53±					Long flat waves. Trace of main phase of distant quake. Heavy micros superimposed.
16	16 Dec.	III _u	o eP _v eP _E eP _N eS _N eS _E eL _N eL _E eL _v M _v M _E M _N F	12 06 31 12 19 09 12 19 15 12 19 18 12 29 44 12 29 46 12 45 56 12 47 07 12 47 30 13 00 38 13 00 43 13 05 21 15 44±					Δ = 9510 km. Minimum values. See discussion in text.
						18½		350*	
						18½	982*	935*	
						18			
17	17 Dec.	I?	e F	19 47± 20 09±					Trace of main phase of distant quake.
18	21 Dec.	I?	eP _E e _N M _E M _N F	19 55 37 19 55 42 19 56 16 19 56 17 20 08±	2½ 3	6	13	Local shock. Time marking device on V out of order.	



No.	Date	Char-acter	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A _E	A _N	A _V	
				h m s	s	μ	μ	μ	
19	1920 25 Dec.	I?	e F	12 25± 12 51±					Long flat waves of main phase of distant quake. Micros especially heavy on N-S.
20	1921 7 Jan.	I?	e F	1 46± 2 02±					Trace of distant quake on horizontal components.
21	4 Feb.	III _r	o eP _{E,V} P _N P _V P _E M _V eS _{E,N} eS _V eL _{N,V} eL _E M _N M _E F	8 23 34 8 30 19 8 30 41 8 30 42 8 30 43 8 30 55 8 35 40 8 35 42 8 39 58 8 39 59 8 41 29 8 41 56 10 21±	3 1/3		11	131	Δ = 3210. Appearance suggests that vibrations were received from different loci along a progressive rupture. Epicenter on Isthmus of Tehuantepec, in Mexico.
22	19 Feb.	I _u ?	e ^{?E} eL ^{?E} F	18 38 59 18 59 05 20 13±	27 24				Trace of distant quake on all components. No phases discernable on N-S and V.
23	21 Feb.	I?	eP ^{?N} eP ^{?E} eS ^{?E} M _E F	15 59 42 15 59 48 16 02 23 16 04 54 16 44±					Shock was recorded while sheets were being changed. Maximum displacement probably on N-S, but value uncertain. Phases very poorly marked.
24	21 Feb.	I?	e F	19 30± 19 54±					
25	27 Feb.	I _u							Chronometer being repaired. No time marks on records. From average rate of drum S-P = 9 3/4' and Δ = 8500 km.
26	5-6 Mar.	III _r	o eP _N eP _{E,V} eS _{E,V} eS _N eL _N eL _E eL _V M _E M _N M _V F	7 24 42 7 28 45 7 28 48 7 32 03 7 32 04 7 32 57 7 32 59 7 33 01 7 34 58 7 35 22 7 36 30 8 36±	15 14 10	406	140	39	Δ = 1920 km.

No.	Date	Char-acter	Phase	Time G. M. C. T.	Period	Amplitude			Remarks	
						A _E	A _N	A _V		
				h m s	s	μ	μ	μ		
27	1921 12 Mar.	I _d	eP _V eP _E eP _N iLM _{E,V} iLM _N F	2 50 35.3 2 50 35.6 2 50 35.7 2 50 39.1 2 50 39.4 2 52±		< 1/2 < 1/2	10	40	13	Δ = 34 km. Felt by a few people in Berkeley.
28	24 Mar.	I?	e F	9 59± 10 41±						Main phase of distant quake. Preliminary tremor obscured by micros.
29	24 Mar.	I?	e F	14 59± 15 43±						Faint record of a distant quake badly obscured by micros.
30	25 Mar.	I?	e ^{?N} e ^{?E} e ^{?V} M _N F	0 36 56 0 37 00 0 37 02 0 42 15 0 56±						Time checks with series of slight shocks felt at Yuma, Arizona.
31	28 Mar.	II _r	o eP _{E,V} eP _N eS _E eS _N e ^{?E} e ^{?N} M _N eL _E eL _N M _E F	7 49 22 7 56 59 7 57 03 8 03 01 8 03 04 8 06 26 8 06 31 8 07 13 8 08 09 8 08 38 8 14 07 9 46±	10 18		171	127	Δ = 4260. Pronounced maximum on N-S during second preliminary tremor.	

THE LICK OBSERVATORY STATION

CONSTANTS

CONSTANTS OF THE STATION

Latitude and longitude of the center of the seismographic room:

$$\phi = 37^\circ 20' 24.''5 \text{ N. Lat.}$$

$$\lambda = 121^\circ 38' 34.'' \text{ W. from Greenwich.}$$

Time. All determinations are reduced to Greenwich mean civil time.

Altitude, 1281.7 meters (4202.25 feet) above mean sea-level.

CONSTANTS OF THE SEISMOGRAPHS

	Period	Magnif.	Damping
Wiechert Seismograph N-S component.....	5.4	40	20:1
Wiechert Seismograph E-W component.....	4.7	85	18:1
Wiechert Seismograph Vertical component.....	3.4	85	10:1



No.	Date	Char-acter	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A _E	A _N	A _V	
				h m s	s	μ	μ	μ	
1	1 Oct.	I?	eL _E	19 07 13					Faint trace of distant quake on horizontal components only.
			eL _N	19 07 22					
			F	19 22±					
2	2 Oct.	I _d	e	0 21 38					Thickening of pen trace on horizontal components only.
			F	0 21 46					
3	5 Oct.	III _d	iP _{ENV}	19 04 39.3		<1"	505	73	Δ = 90 km. First shift of ground to SE and up. Records asymmetric and somewhat tangled. Maximum reported for E-W may not be true maximum because pen left sheet on one side. Felt in San Jose and in neighboring towns. See Berkeley No. 2.
			iL _N	19 04 51.1					
			iLM _E	19 04 51.2					
			iLM _V	19 04 51.5					
			M _N	19 05 06.8					
F	19 15±								
4	6 Oct.	I _d	e	4 53 35					Thickening of pen trace on horizontal components.
			F	4 54 10					
5	13 Oct.	I _d	i	22 51 37					Slight thickening of pen trace on all components.
			F	22 51 44					
6	15 Oct.	I _d	i	0 15 15					Thickening of pen trace on all components.
			F	0 15 22					
7		I?	e [?] _E	8 30 35					Two outstanding displacements occur about a minute apart on E-W. The first of these is the beginning of perceptible motion, and shows a greater amplitude than any succeeding vibration.
			e [?] _N	8 30 38					
			F	9 07±					
8	21 Oct.	I _d	e _E	21 26 25					Minute rapid vibrations. Not recorded on V.
			e _N	21 26 38					
			F	21 27 22					
9	28 Oct.	I?	e _V	13 02 18					Small, irregular, short period waves on all components.
			e _E	13 02 19					
			e _N	13 02 20					
			F	13 16±					
10	3 Nov.	I _d	e _V	0 21 38					Minute short period vibrations superimposed upon longer waves.
			e _N	0 21 43					
			e _E	0 21 47					
			F	0 22 43					

No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A _E	A _N	A _V	
				h m s	s	μ	μ	μ	
11	1920 16 Nov.	I?	e _N e _E F	8 49 20 8 49 51 8 58±					Trace of main phase of distant quake. Not registered on V.
12	16 Nov.	I _d	i F	16 12 03 16 12 20					Thickening of pen trace on horizontal components.
13	17 Nov.	I _d	i F	7 24 20 7 24 31					Thickening and irregularity of pen trace on horizontal component.
14	17 Nov.	I _d	i F	16 09 04 16 09 10					Slight thickening of pen trace on all components.
15	17 Nov.	I _d	e _E e _N i _V F	17 39 31 17 39 41 17 39 42 17 39 46					Slight thickening of pen trace on all components.
16	23 Nov.	I _d	i _E e _N i _V F	20 10 20 20 10 22 20 10 21 20 10 31					Thickening of pen trace on all components.
17	24 Nov.	I _d	e _{E,N} e _V F	15 15 55 15 15 59 15 16 02					Thickening of pen trace on all components.
18	24 Nov.	I _d	e F	23 36 44 23 36 51					Minute rapid vibrations on all components.
19	26 Nov.	I _d	e _{E,N} i _V F	5 20 29 5 20 32 5 20 49					Pronounced thickening of pen trace on all components.
20	28 Nov.	I?	e _E e _N F	10 35 57 10 36 34 10 49±					On horizontal components only. Characteristic period about 10".
21	30 Nov.	I _d	e F	23 21 48 23 21 57					Thickening of pen trace on horizontal components only.
22	2 Dec.	I _d	i _E i _N F	0 02 41 0 02 43 0 02 45					Shifting of pen trace on E-W and slight thickening on N-S. Barely perceptible on V.
23	2 Dec.	I _d	e F	0 04 23 0 04 29					Slight thickening of pen trace on horizontal components. Barely perceptible on V.

No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A _E	A _N	A _V	
				h m s	s	μ	μ	μ	
24	1920 2 Dec.	I _d	iP _{E,N} iL _E iL _N F	22 00 51.6 22 00 55.2 22 00 56.4 22 01 17					Minute, rapid vibrations. Not recorded on V.
25	5 Dec.	I _d	e _N M _N F	11 59 10 12 00 36 12 04±					Not recorded on V. E-W illegible due to over-scoring.
26	21 Dec.	I _d	P _{E,N,V} iL _{E,N} iL _V F	19 55 18 19 55 29 19 55 30 Obscured by following shock.					Δ = 77 km.
27	21 Dec.	I _d	e _V e _{E,N} e _V F	19 57 33 19 57 45 19 57 50 19 59 02					Probably comprises two weak aftershocks of No. 26.
28	22 Dec.	I _d	e _N F	4 22 27 4 23 05					Thickening and irregularity of pen trace on N-S only.
29	23 Dec.	I _d	e F	21 27 18 21 27 48					Weak focal shock registered on all components.
30	25 Dec.	I?	e _N F	12 27 36 12 50±					Trace of main phase of distant quake on N-S only.
31	28 Dec.	I _d	i F	7 56 40 7 56 47					Shifting and thickening of pen trace on horizontal components.
32	1921 3 Jan.	I _d	e F	22 01 52 22 02 01					Slight thickening of pen trace on all components.
33	5 Jan.	I _d	e F	1 01 37 1 01 47					Minute short period vibrations on all components.
34	5 Jan.	I _d	e F	18 41 55 18 42 03					Thickening of pen trace on all components.
35	7 Jan.	I _d	e F	21 16 41 21 16 55					Pronounced thickening of pen trace on all components.
36	8 Jan.	I _d	e F	17 46 35 17 46 44					Slight thickening of pen trace on all components.
37	17 Jan.	I _d	e F	6 34 38 6 34 43					Slight thickening of pen trace on horizontal components only.

No.	Date	Char-acter	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A _E	A _N	A _V	
	1921			h m s	s	μ	μ	μ	
38	31 Jan.	I _d	e F	23 53 28 23 53 36					Pronounced thickening of pen trace on horizontal components.
39	2 Feb.	I _d	e F	1 13 04 1 13 11					Thickening of pen trace on horizontal components.
40	2 Feb.	I _d	e F	1 16 59 1 17 08					Thickening of pen trace on all components.
41	2 Feb.	I _d	e F	1 42 25 1 42 32					Slight thickening of pen trace on all components.
42	3 Feb.	I _d	e F	0 30 45 0 30 50					Slight thickening of pen trace on all components.
43	3 Feb.	I _d	i F	12 52 17 12 52 31					Δ < 10 km.
44	3 Feb.	I _d	i F	13 11 46 13 12 43					Δ < 10 km.
45	4 Feb.	II _r	o eP _N eP _E eS _N eS _E eL _E eL _N M _N M _E F	8 23 23 8 29 34 8 29 37 8 34 28 8 34 29 8 38 36 8 38 46 8 39 36 8 43 37 9 25±					Δ = 3150 km. On Isthmus of Tehuantepec, in Mexico.
46	14 Feb.	I _d	e F	11 51 58 11 52 24					Thickening of pen trace on horizontal components.
47	21 Feb.	I?	eP _N eP _E F	15 59 56 15 59 57 16 34±					Amplitudes very small. Not recorded on V.
48	27 Feb.	I _u	o eP _N eP _E eS _N eS _E e [?] _E e [?] _N eL _E eL _N F	18 23 38 18 35 13 18 35 14 18 44 46 18 44 49 18 53 59 18 54 02 18 57 58 18 58 02 21 17±					Δ = 8270 km. Waves of main phase are very irregular. No definite maximum.

No.	Date	Char-acter	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A _E	A _N	A _V	
	1921			h m s	s	μ	μ	μ	
49	28 Feb.	I _d	e F	16 58 29 16 58 40					Thickening of pen trace on all components.
50	28 Feb.	I _d	e F	21 17 44 21 17 52					Thickening of pen trace on E-W and V.
51	5 Mar.	I _d	e F	1 28 10 1 28 18					Thickening of pen trace on all components.
52	6 Mar.	I _r	eP _E eP _N eL _E eL _N M _E M _N F	7 28 40 7 28 44 7 31 58 7 32 03 7 35 07 7 35 14 8 16±		11 10	23 8	Recorded on V by shift of pen trace.	
53	10 Mar.	I _d	e F	22 39 23 22 39 30					Shifting and thickening of pen trace on horizontal components only.
54	12 Mar.	I _d	eP _{E,N} eL _{E,N} F	2 50 42 2 50 52 2 52 07					Δ = 77 km.
55	14 Mar.	I _d	e F	18 13 50 18 14 04					Thickening of pen trace on horizontal components.
56	21 Mar.	I _d	e _{N,V} F	21 22 37 21 22 44					Slight thickening of pen trace on N-S and V.
57	24 Mar.	I?	e F	15 05± 15 15±					Trace of main phase of distant quake on horizontal components only.
58	25 Mar.	I?	e _N e _E F	0 36 09 0 36 25 0 54±					Phases not determinable.
59	28 Mar.	I _r	o eP _N eP _E eS _{E,N} F	7 49 25 7 56 56 7 56 58 8 02 53 8 59±					Δ = 4170 km.
60	28 Mar.	I _d	e F	12 23 26 12 23 33					Thickening of pen trace on all components.
61	28 Mar.	I _d	e F	21 30 37 21 30 45					Thickening of pen trace on all components.
62	29 Mar.	I _d	e F	1 04 41 1 04 53					Thickening of pen trace on all components.
63	30 Mar.	I _d	e F	17 38 59 17 39 06					Barely perceptible on V.

DISCUSSION OF PARTICULAR EARTHQUAKES

EARTHQUAKE OF DECEMBER 16, 1920, IN CHINA

The epicentral area of this teleseism was in the province of Kan-su, China. Press reports state that the shock was destructive over wide areas. The records obtained at the Berkeley station are striking because of the extraordinarily large amplitudes recorded during the main phase. Unfortunately the Lick station instruments were being overhauled and cleaned at this time and were out of service so that no records were obtained from them.

In marked contrast to the large displacements recorded during the main phase are the exceedingly small amplitudes of the first preliminary tremor. It proved to be very difficult to differentiate the first minute vibrations of this phase from the weak microseisms in progress. On the vertical component sheet the micros were less troublesome and it was possible to fix eP_v with more precision. Evidently the horizontal components of the first few longitudinal waves were so small as to escape detection, for there is a lapse of about seven seconds between eP_v and the inception of the first identifiable P waves on E-W and N-S. Motion continues persistently throughout this phase but the amplitudes remain small. During the latter portion there is a slight increase in the average period of the waves.

It is easy to fix to the nearest minute the time of beginning of the second preliminary tremor on the horizontal components, but it is difficult to locate the arrival of S waves to the nearest second. The change of character is more or less gradual. There is a notable increase of both amplitude and period over those characteristic of the P waves. Moreover, this increase of amplitude and period continues during the phase, and contributes to the difficulty of identifying the first L waves. The earliest S waves apparently failed to register on V.

It is impossible to be sure of the time of beginning of the main phase. It is possible to trace back from the first regular waves

a series of long period, irregular vibrations which certainly represent the first portion of the main phase, but the early part of this series is so completely obscured by the superimposed S waves that its time of beginning is problematical. The regular waves increase rapidly in amplitude while the period is somewhat diminished. The motion never becomes simply sinusoidal and the amplitudes fluctuate notably. On N-S, amplitudes of over 600 microns are common for thirty minutes or more. The displacements recorded on V during this phase are markedly smaller than those registered on the horizontal component sheets. M_v occurs at 13^h 00^m 38^s with an amplitude of 350 microns. Only minimum values for the maximum horizontal displacements can be assigned because the pens were thrown off the sheets. At 13^h 00^m 43^s a displacement of 982 microns is recorded on E-W. Returning from this peak the pen crossed the median line, continued to the edge of the paper and to an unknown distance beyond, returning after about a minute and a half. It so happens that the distance from the median line to the edge of the sheet is slightly less than 982 μ , so that the minimum value for the maximum amplitude is that noted above, although it is practically certain that this displacement was exceeded by the swing which carried the pen off the sheet. Conditions were very similar on N-S a few minutes later. At 13^h 05^m 21^s a displacement of 935 microns was recorded, and the succeeding vibration took the pen beyond the edge of the paper on the opposite side of the median line. This latter distance is but little less than 935 microns and the appearance of the record strongly suggests that the pen continued considerably farther before beginning the return swing. The strong motion is very persistent. Displacements of 50 microns are fairly common as late as an hour after the beginning of the main phase. The end of discernible movement comes about three and one-half hours after the beginning of the record.